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ENVIRONMENTAL HEALTH SERIES

Radiological Health

STANDARDS OF PERFORMANCE
FOR
FILM BADGE SERVICES

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

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59

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**STANDARDS OF PERFORMANCE FOR
FILM BADGE SERVICES**

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Public Health Service
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Washington, D.C. 20201

FOREWORD

The formulation of acceptable standards for film badge services used for recording radiation exposure should be regarded as an important accomplishment by those whose official and professional responsibilities require that they attempt to achieve for the U.S. population the social and economic benefits inherent in many radiation applications and at the same time minimize the potential risk.

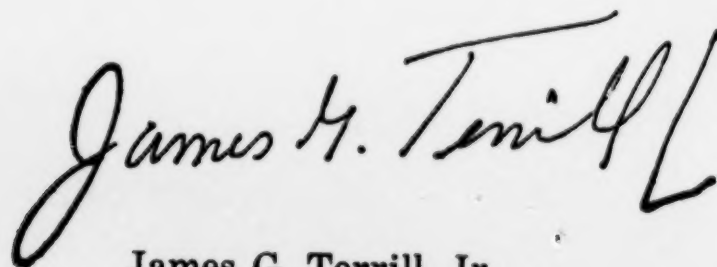
The importance of accuracy in the measurement of radiation exposure to radiation users and the general population has been long recognized by health and regulatory agencies, by the users of film badges, and by film badge services.

In response to this need, the Public Health Service's Division of Radiological Health in 1963 began to support efforts of the National Sanitation Foundation to determine the feasibility of developing standards and to initiate a program for examining the performance of film badge services. This support, which included technical as well as financial assistance, was provided by the Division's Technical Operations Branch under the direction of Donald J. Nelson. Invaluable technical support also has been rendered by other Federal agencies, a large segment of the film badge industry, several State health departments, many of the national laboratories dealing with nuclear energy, and the military services.

As evidenced in this report, the National Sanitation Foundation has developed evaluation procedures sufficiently broad in scope to serve as a basis of performance control limits for film badge services. Evaluation procedures have been applied in a test involving approximately 2,000 film badges from 25 different organizations. The plan calls for film badge services to be examined on a recurrent basis and includes special recognition, in the form of a seal of approval, for those services which demonstrate accuracies within the specified control limits.

The standards have the approval of the Division of Radiological Health of the Public Health Service and are recommended for consideration by users in the medical and dental X-ray field, in-

dustrial users of radiation, and State and Federal agencies responsible for licensing and safe use of radiation machines and radioactive materials.

A handwritten signature in cursive script, reading "James G. Terrill, Jr.", with a large, stylized flourish at the end.

James G. Terrill, Jr.
Deputy Chief
Division of Radiological Health

PREFACE

The research aspects of the program described in this report were sponsored primarily by U.S. Public Health Service Contract No. PH 86-63-198 with the National Sanitation Foundation. Additional funds were donated to the Foundation by commercial film badge services. The routine film badge evaluation program, which began in August 1966, will be sponsored on a nonprofit fee basis.

The film badge program described is intended to be a dynamic one. Criticisms and suggestions concerning the program are invited. Please address all comments to The National Sanitation Foundation, School of Public Health, University of Michigan, Ann Arbor, Michigan 48104.

Representative products and manufacturers are named for identification only, and listing does not imply endorsement by the Public Health Service and the U.S. Department of Health, Education, and Welfare.

THE AUTHOR

At the time of the writing of this report, Dr. Barber was Assistant Professor in the Department of Environmental Health, School of Public Health, The University of Michigan, Ann Arbor, Michigan. He was also Project Director of the research leading to the establishment of the Standard presented here. He is presently Associate Professor in the College of Medical Sciences, School of Public Health, University of Minnesota, Minneapolis, Minnesota.

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ABSTRACT

Standards of performance for film badge services are of general concern to film badge services, users of these services, and regulatory agencies. A quality control program self-imposed by film badge services, but involving all of these groups, is described.

Film badge performance evaluation procedures have been devised to generate data sufficiently broad in scope to serve as the basis for control limits. The evaluation procedures and control limits will be applied in periodic examinations of film badge services. Irradiation procedures, dosimetry, and a measure of film badge accuracy appropriate to the practical use of film badges are discussed.

Approximately 2,000 film badges were irradiated with various types and energies of radiation. Exposures ranged from 0.002 to 497 roentgens. Film badge services (1) helped design the test procedures, (2) submitted badges for exposure, (3) interpreted exposures, and (4) assisted in determining provisional performance control limits. All services were informed of the test procedures to be used in the test. However, the services did not know which badges were exposed to what type, energy, or dose of radiation. A measure of accuracy, called an "error factor," was determined for each service for each type and energy of radiation in the test. These error factors are tabulated to show the accuracy of the film badge services tested. Frequency distributions of the error factors served as the basis for selection of control limits used to define acceptable performance.

Administrative procedures for periodically evaluating film badge service performance and for recognizing acceptable performance are also described.

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STANDARDS OF PERFORMANCE FOR FILM BADGE SERVICES

INTRODUCTION

The ability of film badge services (commercial, governmental, and other) to report radiation exposures with suitable accuracy has been a matter of general concern for some years. A number of independent studies have provided evidence in support of this concern (1-5).

Other expressions of this concern were the "Notice Regarding the Need for Establishment of a Film Dosimetry Calibration Laboratory" issued by the Atomic Energy Commission in 1963 and the State of Illinois Radiation Monitoring Act, approved on August 16, 1963, which prohibits any person or firm from providing film badge radiation monitoring services in the State without approval from the Department of Public Health, State of Illinois (6, 7).

Organizations using and/or providing film badge services encompass a wide variety of interests. Among these organizations are the U.S. Public Health Service, the U.S. Atomic Energy Commission, the military services, commercial film badge services, State health agencies, and a variety of film badge users.

Informal discussions with leaders in environmental health control prompted the National Sanitation Foundation (the Foundation) to convene a meeting of representatives from several commercial film badge services on February 1, 1963. This meeting was for the expressed purpose of exploring the desirability and feasibility of the Foundation's undertaking the development of performance criteria for such services. The consensus of those who attended the meeting favored development of a quality control program through the Foundation. An exploratory program was outlined at the meeting and distributed to the 17 commercial film badge services in the United States. Of the 13 replies received, 10 favored the exploratory program as it had been outlined.

This response from the industry, the informal support from State health agencies and the specific interest from the U.S. Public Health Service, stimulated the Foundation to prepare and submit

a contract request to the U.S. Public Health Service in June 1963. The contract subsequently granted was for the purpose of investigating the feasibility of establishing performance criteria for film badge services.

The Foundation, following its established methods and policies, invited all concerned parties to participate and formed a Foundation Advisory Committee on Film Badge Services. Participating professional organizations, governmental agencies, commercial services, and their official representatives are listed in the Standard (Appendix).

The Foundation Advisory Committee on Film Badge Services during the fall of 1965 recommended the adoption of the proposed Foundation Standard for Film Badge Services. Following established procedures, the Advisory Committee submitted the proposed Standard for final opinion and ballot to the Foundation's Council of Public Health Consultants (listed in the Appendix). The Council unanimously approved the Standard and the Foundation formally adopted it on May 4, 1966.

The objectives of the Foundation program are:

1. to improve film badge performance,
2. to provide a film badge service performance standard and to modify this Standard as improvements in film badge services are made,
3. to enable film badge services to undertake a self-imposed quality control program, and
4. to identify for the public those services that demonstrate ability to perform consistently with the Standard.

The Foundation believes that film badge performance can be improved and brought to a satisfactory state by development and application of a quality control program for film badge services.

A Foundation Standard provides for a complete review of the Standard at intervals of not more than 3 years to determine what changes, deletions, or additions, if any, are necessary to keep the Standard current and effective. These reviews are conducted by appropriate representatives from the industry, public health, and user groups. Final adoption of revisions is in accordance with the procedures established by the Foundation.

The Foundation is a nonprofit organization which serves as a meeting place and clearinghouse for the development of standards applicable to products and services consistent with the health needs of man. Such standards provide for self-regulation rather than regulation through ordinances, inspections, and law enforcement alone. Representatives of top management from producers, users, and regulatory agencies are brought together through the

Foundation to formulate methods to evaluate performance of products and services, and to establish control limits which together make up a Foundation Standard. After a mutually acceptable standard is formulated, products and services are examined in accordance with the Standard by the National Sanitation Foundation Testing Laboratory, a separate corporation wholly owned by the Foundation. The testing Laboratory was established to fulfill the need for periodic examination of products for conformance with control limits established in Foundation Standards. Products which demonstrate compliance with these control limits are eligible to use the "nSf" Seal of Approval. Use of the copyrighted "nSf" Seal of Approval is restricted to those products and services which conform to both the requirements of the Standard and the policies governing Seal of Approval programs.

Listings of products and services, which have demonstrated satisfactory compliance with Foundation Standards, are published and widely distributed.

EVALUATION PROCEDURES

The National Sanitation Foundation Standard No. 16 describes film badge service evaluation procedures and performance control limits generally acceptable to film badge services, users of these services, and regulatory agencies (Appendix). Practical considerations require that these evaluation procedures:

1. involve the minimum number of film badges consistent with the production of significant information, and
2. be sufficiently broad in scope to provide a basis for control limits.

The procedures described in the Standard are to be applied on a routine basis. To test the appropriateness of the Standard and to provide sufficient data to serve as the basis for the control limits in the Standard, an extensive test of film badge services was carried out in December 1964. The details of this test follow.

A FILM BADGE PERFORMANCE TEST

Scope

The Foundation invited commercial, Federal, and other film badge services to submit film badges for test irradiations. In addition, the U.S. Public Health Service arranged to have four State health departments obtain badges from four different services. Three of these four services also participated directly in the test.

The types and numbers of organizations that submitted film badges for this test are listed below:

Commercial	12
Federal agencies	8
State health departments	4
Private	1

One film badge service provided two different types of badges, which brought the number of sets to 26. Each set consisted of 80 badges, except for those film badge services that do not provide neutron monitoring badges, in which case a set consisted of 69 badges. The test involved a total of about 2,000 individual film badges.

General Procedures

Badges received from 19 organizations were irradiated beginning December 1, 1964. These badges were returned to suppliers on December 9, 1964. Badges received from six organizations were irradiated beginning December 21, 1964. These badges were returned to suppliers on December 29, 1964.

All the badges were kept in an air-conditioned building (23° to 27°C, 10- to 50-percent relative humidity) from the time they were received until they were returned to the suppliers 8 days later. Each badge was marked with a code, on a removable label, to simplify tabulation of data in a manner that would prevent the identification of individual services from published results.

Calibrations of irradiation rates were made, at the film badge positions, using the techniques described in the Appendix. Measurements of dose rate as a function of distance from the sources of radiation showed that backscatter error was less than ± 5 percent for all irradiations.

For beta, gamma, and neutron irradiations, source-to-film distances varied slightly because of differences in badge construction. Nominal source-to-film distances were 20 cm for beta, 50 cm for gamma, and 20 cm for neutron irradiation. Delivered irradiations were corrected for inverse square errors produced by differences in badge construction. For gamma exposures the correction factors ranged from 1.01 to 1.05. For beta and neutron irradiations the correction factors ranged from 1.04 to 1.13. The target-to-film distance for all X-irradiations was 199 cm. No inverse square corrections were necessary for X-irradiations.

Irradiations

The irradiation schedule is shown in table I.¹ There were no replicate exposures of badges within any radiation group in table I. The dose rates for gamma, beta, and neutron irradiations were constant. Dose rates for X-irradiations varied linearly with beam current and could, therefore, be controlled conveniently. X-ray exposures were monitored with a Victoreen Roentgen Ratemeter to be certain that the X-ray machine operated consistently for all exposures.

The extrapolation chamber used for beta radiation dose measurements was designed and fabricated at the University of Michigan. The extrapolation chamber measurements showed that between 18 and 20 cm from the strontium-yttrium 90 source, the dose rates varied inversely as the square of the distance from the source (figure 2, Appendix). Hence, differences in dose delivered to badges of various design could be calculated reliably.

The dose rate 20 cm from the beta-ray source was measured as a function of angular displacement from the source center line with both the extrapolation chamber and with photographic film. The results of the two methods of measurement agreed within ± 5 percent. The dose delivered to film badges per revolution of the exposure rig was obtained by integration of the curve in figure 4 of the Appendix.

The neutron emission rate from the plutonium-beryllium neutron source was measured in a MnSO_4 bath at the National Bureau of Standards. The accuracy of this measurement is ± 2.5 percent (8). The flux density at a distance of 20 cm from the source was measured with a proton-recoil counter as a function of angle from the axis of the source, which is cylindrical (figure 6, Appendix). Within the precision of the measurement, ± 5 percent, the emission was found to be isotropic. The measurements showed that the inverse square law holds at this short source-to-film distance. Consequently, neutron flux densities were calculated from the source calibration provided by the National Bureau of Standards.

Analysis

The reported exposures (Y) were plotted against the delivered exposures (X) on log-log coordinates for each film badge service and each of the 10 groups of irradiations shown in table II. Figure 7 (Appendix) is an example of such a plot. The line $X=Y$ represents perfect performance.

¹ Arabic numerals are used for figures and tables that appear in the Appendix. Roman numerals and letters are used for all other figures and tables.

Table I. Film badge irradiations^a

Group	Radiation	Added filter (mm)	kVp or source	a. 1st HVL ^b b. 2nd HVL (mm)	Effective energy ^c (keV)	Irradiation range	Total number of film badges	Number of film badges receiving >20 mrem ^d
1.....	X-ray	1 Al	68	a. 1.05 Al b. 2.00	23	6-288 mR	9	6
2.....	X-ray	1 Cu + 1 Al	200	a. 1.35 Cu b. 2.35	90	3-186 mR	9	6
3.....	X-ray	1 Sn + 1 Cu + Th II ^e	270	a. 4.10 Cu b. 5.60	175	9-287 mR	9	8
4.....	X-ray	1 Sn + 1 Cu + Th II ^e	270	a. 4.10 Cu b. 5.60	175	2-497 R	4	4
5.....	Gamma	Capsule only ^f	¹³⁷ Cs	—	662	11-305 mR	9	8
6.....	Beta	Capsule only ^g	⁹⁰ Sr-Y	—	—	23-276 mrad ⁱ	9	9
7.....	Beta + gamma	Capsule only ^g	⁹⁰ Sr-Y + ¹³⁷ Cs	—	662	28-136 mR	9	9
8.....	X-ray + gamma	1 Al capsule only ^f	68 ¹³⁷ Cs	1.05 Al —	23 662	17-390 mR	9	8
9.....	Fast neutron	Capsule only ^h	Pu-Be	—	—	17-228 mrem	9	8
10.....	None	Two controls for neutron film badges + two controls for all others				none	4	0

^a Relative humidity during irradiations varied from 14 percent to 48 percent. Temperature varied from 23° to 27° C.

^b Half-value-layer

^c Based on first HVL

^d The decision to eliminate from the test all doses less than 20 mrem was made after all irradiations had been completed.

^e Th II=0.4 mm Sn + 0.25 mm Cu + 1.0 mm Al.

^f The ¹³⁷Cs source is encapsulated in 30 mils 303 S.S. + 30 mils 321 S.S.

^g The ⁹⁰Sr-Y source has a 21 mg/cm² aluminum end window.

^h The neutron source is encapsulated in 100 mils of tantalum + 30 mils of 304 S.S.

ⁱ Measured in air

Results for each of the radiations in table II for each film badge service were analyzed as follows. First, the reported exposure geometrically farthest from the perfect performance line was noted and omitted from further consideration (Discussion). The point that lay next farthest from the line of perfect performance was then designated as the "error factor point" (figure 7, Appendix).

The "error factor," Y_e/X_e , was determined by the coordinates of the error factor point. This factor was used as the measure of accuracy of a service for each of the radiations in table II. Note that the error factor may be greater than 1.0, as in figure 7 (Appendix), or less than 1.0. The upper error band has the equation $X=(X_e/Y_e)Y$, and the lower error band the equation $X=(Y_e/X_e)Y$. Although the error bands are geometrically equidistant from the perfect performance line, they do not represent the same percentage error. To illustrate: an error factor of either 2.0 or 0.5 means that all but one of the points fall between the limits -50 percent and +100 percent.

Error factors were determined separately for the gamma and beta components of mixed beta and gamma irradiations.

Results

Reports from most of the film badge services were received within 2 weeks, but the range was 5 days to 3 months. The data from the film badge services were tabulated according to the following rules:

1. Data prefixed by "less than" or "minimal" were tabulated as zero.

2. In cases where the services identified the type or energy of the radiation incorrectly, the reported data were compared with delivered irradiations for the radiation actually used to expose the badges; that is, if a service reported a 23 keV X-irradiation as beta radiation, the dose was tabulated as 23 keV X-rays.

3. For those services which reported beta radiation doses in obsolete units (mrep), the data were examined assuming that 0.93 mrad is equivalent to 1 mrep. In future tests a more recent factor, 0.96 mrad per mrep, will be used (9). The error introduced by this difference in conversion factors is negligible compared to errors in interpretation of beta irradiations.

4. For exposures involving mixtures of 23 keV X-rays and gamma rays, only the total reported dose was tabulated, for reasons discussed later.

5. Reported values of total neutron flux (fluence) were con-

verted to mrem by dividing by 2.6×10^4 (table 1, Appendix), unless the film badge service stipulated a different conversion factor.

6. Reports on all badges which had actually received less than 20 mrem were omitted from the tabulation.

Reported versus delivered irradiations were plotted on log-log paper for each test participant for each radiation listed in table II. After irradiations were completed, it was decided to include in the analysis only delivered irradiations greater than 20 mrem. Consequently, a few of the data points in the test were discarded.

Table II lists the error factors determined from the test. The asterisks in the table indicate error factors which fall outside the control limits in table 4 (Appendix). Dashes indicate that the service either did not offer interpretations for the specified radiation or the service was not tested for the indicated radiation.

Satisfactory Performance Limits

A number of committees composed of representatives from industry, government, and universities (table III) reviewed the results of this test to determine how performance could best be measured and what limits should be placed, provisionally, on satisfactory performance. The consensus of these committees was as follows:

1. The data generated in the test reported here are sufficient to establish provisional control limits for a routine testing program.
2. The error factor (figure 7, Appendix) is an adequate measure of performance for present purposes, although consideration should be given to a statistically more significant method of analysis.
3. The performance limits (table 4, Appendix) constitute satisfactory control limits for the present.

The proposed control limits were determined as follows:

1. The pooled frequency distribution of all the error factors in table II was examined. The error factors 0.40 and 1.60 were selected arbitrarily from figure A to be reasonable values for control limits for the film badge service industry as a whole. These error factors were chosen to encompass approximately 80 percent of the error factors less than 1.80 but greater than 0.20.
2. The frequency distributions of the error factors for each type and energy of radiation in table II were then examined individually and were compared qualitatively with the pooled distribution. The control limits, chosen from the pooled distribution (figure A), were modified by (a) expanding the control limits if

Table II. Error factors (encompassing all but one of the data points) for irradiations greater than 20 mrem

Radiation											
Service code	23 keV X	90 keV X	175 keV X low exposure	175 keV X high exposure	Beta	Gamma	β of $(\beta + \gamma)$	γ of $(\beta + \gamma)$	X + γ	Fast neutrons	Total asterisks
1.....	0.80	*2.06	0.84	*0.50	*3.64	*0.22	*0.01	*0.04	*0.49	—	7
2.....	*2.29	0.87	0.76	0.85	1.34	*0.69	1.58	*1.43	1.79	*0.04	4
3.....	1.14	1.02	0.90	0.66	1.43	0.81	1.30	0.80	0.85	0.76	0
4.....	*2.18	0.71	*0.12	*0.44	*1.52	*0.59	1.56	*0.65	1.36	2.00	6
5.....	0.79	*0.41	0.76	*>0.61	*1.74	1.31	*0.01	*0.43	*0.44	*0.02	7
7.....	*0.22	0.83	*0.53	0.83	*2.50	0.82	*3.35	0.89	*0.52	1.26	5
8.....	0.87	0.62	1.59	*1.68	1.30	*0.59	1.37	0.89	0.59	0.67	2
9.....	*3.00	0.61	*0.46	*0.36	1.41	0.77	*0.02	*0.64	*0.44	*6.70	7
9b.....	*0.54	0.61	*0.42	*0.02	*0.06	0.85	*0.01	*0.65	—	*4.42	7
11.....	1.32	1.03	0.83	1.05	1.09	0.82	0.85	0.72	1.10	1.59	0
12.....	0.84	*0.46	*0.50	0.63	1.41	0.80	1.77	0.82	0.83	0.80	2
13.....	0.75	0.64	*0.53	0.67	1.28	0.76	*0.01	*0.66	0.73	0.72	3
14.....	0.79	1.61	1.30	*0.52	1.29	0.88	1.46	1.12	*0.49	1.30	2
15.....	1.05	*0.57	0.77	1.09	*0.10	0.78	0.87	0.89	0.58	*0.23	3
16.....	1.50	0.88	0.68	1.15	0.93	1.22	0.61	1.29	0.64	*3.14	1
16b.....	1.37	0.92	0.75	0.91	1.22	1.19	0.81	*1.45	—	—	1
17.....	0.75	0.71	*0.45	0.67	1.08	0.78	1.30	0.73	—	1.31	1
18.....	*0.31	*0.24	*0.23	*0.07	*0.13	*0.33	—	—	*0.22	—	7
19.....	0.80	0.60	*0.54	0.70	*2.22	0.82	*2.45	*0.29	0.63	1.92	4
21.....	*2.04	*2.82	*2.16	0.73	*2.01	*2.55	0.64	1.19	*2.90	*0.01	7
22.....	*0.42	1.59	0.64	*>26.3	*0.43	*0.33	*0.02	*1.78	*0.24	*0.01	8
23.....	1.09	*3.94	1.25	*>1.20	*0.04	1.29	1.90	1.10	*0.52	*0.43	5
23b.....	*0.11	0.79	1.08	1.40	*0.05	1.27	0.96	1.10	*0.48	*0.34	4
24.....	1.27	0.68	1.58	*2.10	0.86	0.85	0.81	1.37	0.58	0.68	1
25.....	*2.09	1.67	*0.42	*>1.82	0.69	*0.01	*0.02	*1.85	*2.27	*2.57	8
26.....	0.90	*0.48	*0.54	0.80	0.87	0.87	1.22	0.86	—	0.59	2
Total asterisks.....	10	8	12	12	12	8	9	11	11	11	104

Notes: Asterisks mean the error factor falls outside proposed control limits in table 4.
Dashes mean the service either did not provide reports for the indicated radiation or was not tested for the indicated radiation.
A "b" after the service code identifies film badges obtained through State health departments. Film badge services were not advised of the use of these badges.

Table III. Organizational affiliations of committee representatives who attended meetings

- 1. Film Badge Companies**
 - AND, Inc.
 - Eberline Instrument Corp.
 - Gardray Film Badge Service
 - Nuclear Chicago Corp.
 - Nucleonic Corporation of America
 - Radiation Detection Co.
 - R. S. Landauer, Jr. and Co.
 - Technical Associates
 - T. M. Gaines Co.
 - Tracerlab, Inc.
 - U.S. Testing Company, Inc.
- 2. Industry**
 - Eastman Kodak Co.
 - E. I. du Pont de Nemours and Co.
 - General Dynamics, Ft. Worth
- 3. Military Services**
 - Department of the Air Force
 - Department of the Army
 - Department of the Navy
- 4. National Bureau of Standards**
- 5. National Laboratories and Atomic Energy Commission Prime Contractors**
 - Argonne National Laboratory
 - Brookhaven National Laboratory
 - Idaho Operations Office, H. and S. Division
 - Lawrence Radiation Laboratory
 - Los Alamos Scientific Laboratory
 - Pacific Northwest Laboratory
- 6. National Sanitation Foundation**
- 7. Professional Organizations**
 - The Association of State and Territorial Health Officers
 - Conference of State Sanitary Engineers
 - American Public Health Association
- 8. Public Health Service and Atomic Energy Commission**
 - Division of Biology and Medicine, U.S.A.E.C.
 - Division of Radiation Protection Standards, U.S.A.E.C.
 - Division of Operational Safety, U.S.A.E.C.
 - National Institutes of Health, U.S.P.H.S.
 - Division of Radiological Health, U.S.P.H.S.
 - X-ray Exposure Control Laboratory, U.S.P.H.S.
- 9. State Departments of Public Health**
 - Illinois Department of Public Health
 - Kentucky Department of Health
 - New York Department of Health
 - Michigan Department of Health
- 10. Universities**
 - University of Michigan
 - University of Pittsburgh

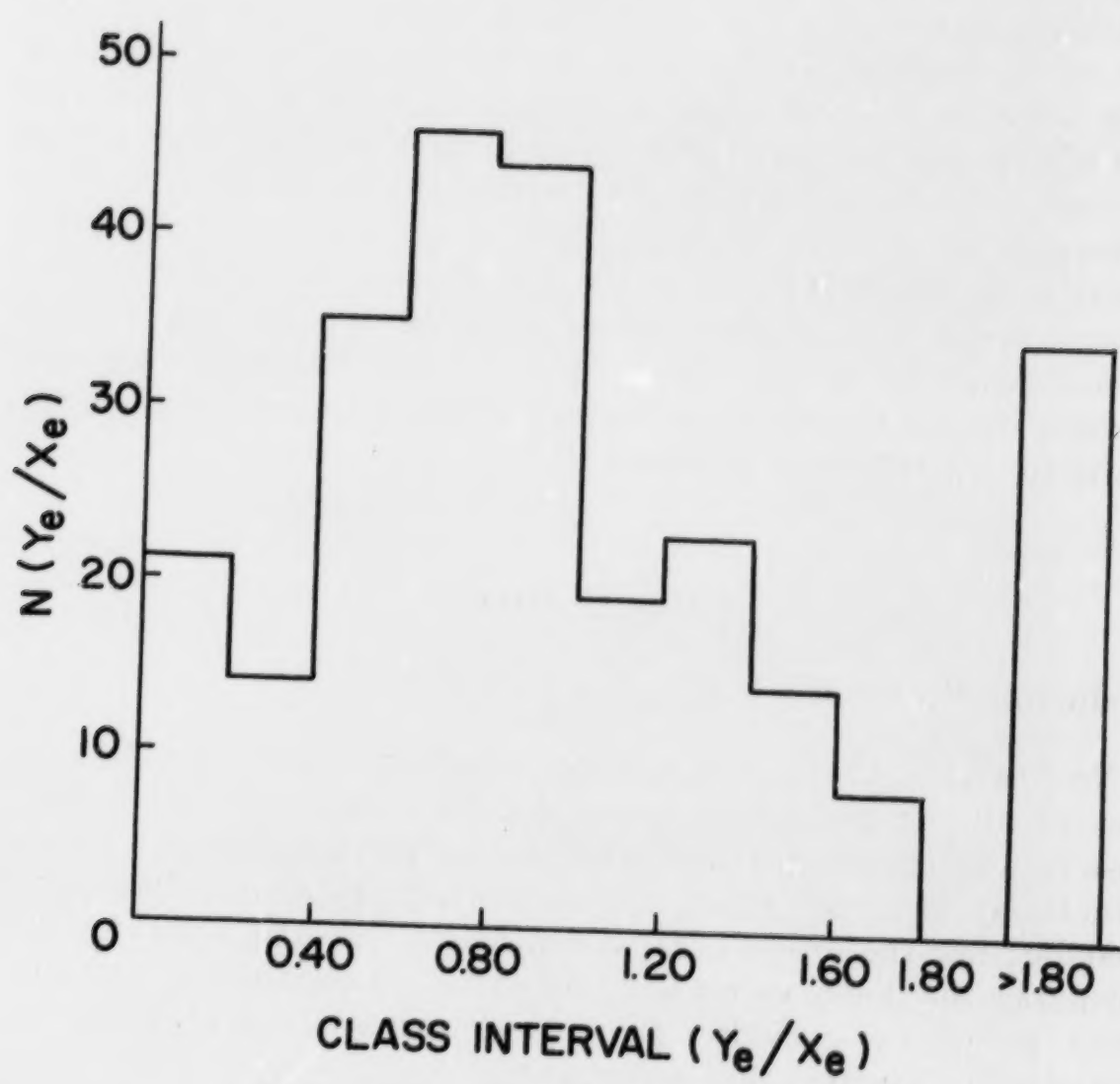


Figure A. Pooled distribution of Y_e/X_e .

the error factors for the radiation group in question appeared to be more widely distributed than the pooled distribution, or (b) narrowing the control limits if the error factors for the radiation in question were less widely distributed than the pooled distribution.

Although the method of determining control limits was empirical and qualitative, the data in table II show that 82 percent of all the error factors fall within the control limits in table 4 (Appendix), a reassuring check on the method.

After adjusting the control limits it developed that about one-half of the services produced results within the control limits in table 4 for individual radiation groups in table II. About one-half of the services demonstrated error factors which fell within the control limits for five or more radiation categories.

Because the frequency distribution of error factors in any one radiation group in table II involved at most 26 error factors and because services were not consistently good or poor from one radiation category to another, it is not surprising that only two services demonstrated error factors which lie within the control limits for all radiation groups.

DISCUSSION

Evaluation Procedures

No practical evaluation procedure can encompass all the energies of all the radiations, in all combinations, over all possible dose ranges, under all possible environmental conditions. Special situations do occur where the described procedures have little bearing; but the procedures will measure film badge service performance for the large majority of exposure conditions. Irradiations purposely excluded from the evaluation procedures are discussed in the next few paragraphs.

Thermal neutron exposures were not included in the evaluation procedures because conventional neutron shields reduce the thermal neutron flux in most situations to the point where gamma radiation is limiting.

A mixture of fast neutron and photon radiations was not included in the evaluation procedures because nuclear track emulsions are so insensitive to high energy photons (10), and because beta-gamma films are so insensitive to fast neutrons (11, 12), that no interference will arise in most exposure situations.

The response of a film badge to beta radiation depends on the

angle at which the beta particles strike the badge (13). To a lesser extent this is also true of neutron, gamma, and X-radiations. The degree of this dependence is largely determined by badge construction. It was considered impractical to include a determination of angular dependence in the initial evaluation procedures.

Superficial and penetrating radiations are defined in terms of depth-dose distribution in soft tissue (14):

Superficial=

dose at 5 cm depth $\leq \frac{1}{6}$ surface dose.

Penetrating=

dose at 5 cm depth $\geq \frac{1}{6}$ surface dose.

Consequently, superficial radiations include beta radiation of all energies and photons with effective energies less than about 20 keV.² Even though beta and low energy photons are both superficial radiations, it is necessary that film badge services distinguish between them because they produce different film densities per unit dose.

The greatest difficulty in making the distinction arises when beta radiation of maximum energy greater than 0.8 MeV and X-rays of effective energy less than 250 keV occur together (13). However, this mixture is rarely encountered in practice. More likely combinations are either: (1) mixtures of low energy X-rays with high energy X-rays or gamma rays or (2) beta rays with gamma rays. The evaluation procedures provide for these latter mixtures.

Only X-rays were used for exposures greater than 600 mR. The use of X-rays for the large exposures is a more severe test than would be the case with cesium 137 gamma rays because the X-rays produce a greater optical density per unit exposure than cesium 137 gamma rays.

Phillips (15) has reported that differences between exposure and calibration geometries may introduce errors as large as ± 70 percent into interpretation of badges exposed to mixed radiations. The magnitude of the error depends upon the gamma ray energy used. Consequently, services that base interpretation of isotropically exposed film badges upon a set of calibration films exposed under narrow beam conditions are likely to show various degrees of accuracy depending upon whether the source used for film calibrations is cobalt 60 or cesium 137. Although errors in interpretation caused by geometry are believed to be larger for cobalt 60

² Sources of low energy photons include scattered X-rays, dental X-rays, and X-rays from diffraction and spectrographic units.

than for cesium 137 exposures (15), it may be necessary to add cobalt 60 exposures to these evaluation procedures because a number of film badge users and services use this isotope as a standard of reference.

An arbitrary degree of freedom was introduced into the test by ignoring the reported irradiation farthest from the perfect performance line. This was done to reduce the likelihood of a service's failing a subsequent test on a purely statistical basis. If the point farthest from the perfect performance line had been used as the basis for control limits, chance would play a stronger role in the *failure* of services to meet the control limits in subsequent tests. On the other hand, had the point closest to the perfect performance line been used, the likelihood of *success* in future tests, for purely statistical reasons, would be high. This rationale is intuitively obvious, but more tests will have to be made before the probability of successes in repeated tests can be determined statistically.

Extensive discussion by people who reviewed the evaluation procedures and the results of the test indicated that the simple analysis described is as useful as any other. These people also accepted the arbitrary omission of the reported dose farthest from the actual dose in each group of badges. This omission has implications for personnel dosimetry that will require careful evaluation.

A number of methods of analyzing the data were examined, but it developed that the simple analysis described proved sufficient for the present. The analysis does not require replicate exposures; it is simple and it permits a wide range of exposures to be examined with a small number of badges. Further, it is difficult for film badge services to anticipate the results.

Test Results

The accuracy of film badge services was examined to determine levels of performance when irradiations are made in a prescribed manner. No attempt was made to evaluate variation caused by errors introduced by the following:

1. film-to-film differences in emulsions,
2. differences in mailing time, temperature or relative humidity during transit,
3. differences in types of film used by services,
4. badge design differences between services,
5. badge construction variations within services,
6. energy of radiation used for calibration by services, and
7. geometry used by services for calibration.

Although all of these errors affect the accuracy with which a service can report irradiations, compensation for them is a part of the film badge service business. Therefore, evaluations of performance of services should not include compensation for such errors.

The wide variation observed in neutron irradiation reports is caused, in part, by differences in factors used to convert n/cm^2 to mrem. Factors used by film badge services to convert n/cm^2 to mrem ranged from 1.4×10^4 to $2.88 \times 10^4 \text{ n/cm}^2\text{-mrem}$. For plutonium-beryllium neutrons the spectrum-weighted conversion factor is $2.6 \times 10^4 \text{ n/cm}^2\text{-mrem}$ (16). This is the same factor that the AEC applies to 5 MeV neutrons (17) and is the factor used by the Foundation. If services were to use this factor for fast neutrons, variations in the error factor for fast neutron irradiations could be reduced by at least a factor of 2.

The analysis of data for the gamma-plus X-radiation group of badges, table I, involved the total delivered and reported exposures because only two of the film badge services that participated in the test distinguished between low energy X-rays and high energy gamma rays. Most services, though they distinguished between gamma and X-radiation exposures, reported that X-ray exposures were less than about 200 keV and indicated that the gamma component was of higher energy. From a dosimetric point of view such a distinction is of little value to the film badge user. Hence, the gamma-plus X-radiation exposure group served a useful purpose in the test only to the extent that it provided a group of films, exposed to mixed energies of electromagnetic radiation, which were more difficult to interpret than films exposed to a single energy or type of radiation.

The control limits in table 4 (Appendix) are comparable with the interim control limits proposed by the Atomic Energy Commission in 1963 (6). This is not to suggest that the control limits proposed either by the Foundation or the AEC represent satisfactory performance in personnel dosimetry. The control limits reflect only the present level of performance of film badge services.

Table II shows that there is a rather broad gap between the better and the poorer services. The number of services, which show error factors between control limits, would not change significantly even if the control limits in table 4 (Appendix) were broadened by a factor of 2.

CONCLUSIONS

Evaluation procedures which are considered practical and adequate have been devised to test film badge service accuracy.

The evaluation procedures have been used in a test of film badges provided by 25 different organizations. The data so obtained give the most complete picture available of the present performance of film badge services.

On the basis of the data obtained in this work, committees representing a wide variety of interests have recommended provisional limits for satisfactory performance in terms of a measure of accuracy called the "error factor."

The evaluation procedures and the film badge performance control limits have been formulated into the National Sanitation Foundation Standard No. 16 (Appendix).

SUMMARY

Evaluation of the ability of film badge services to report accurately irradiations made with various types and energies of radiation is needed by film badge users, regulatory agencies, and film badge services. The work reported here was undertaken in response to this need and because there appeared to be a need for a meeting of minds with regard to the character of an acceptable program for examining the performance of film badge services. The work has been carried out under the auspices of the National Sanitation Foundation with the cooperation and support of the U.S. Public Health Service, a large segment of the film badge service industry, several State health departments, several of the National Laboratories, the military services, and other Federal agencies.

Evaluation procedures have been developed to generate data sufficiently broad in scope to serve as a basis for performance control limits. The evaluation procedures have been applied in a test involving approximately 2,000 film badges from 25 different organizations. This test and the efforts of representatives of film badge services, customers of these services, public health and radiation protection enforcement agencies have resulted in the establishment of control limits for film badge service accuracy. The plan calls for film badge services to be examined on a recurrent basis and includes special recognition, in the form of a seal of approval, of those services that demonstrate accuracies within specified control limits.

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APPENDIX

**THE NATIONAL SANITATION FOUNDATION
STANDARD NO. 16**

and

Administrative Policy for Film Badge Evaluations

**THE NATIONAL SANITATION FOUNDATION
STANDARD NO. 16**

**relating to
FILM BADGE SERVICES**

**Prepared by
The National Sanitation Foundation Advisory Committee
for
Film Badge Services**

**The National Sanitation Foundation
Headquarters
School of Public Health—University of Michigan
Ann Arbor, Michigan**

Effective Date: May 4, 1966

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THE NATIONAL SANITATION FOUNDATION
STANDARD NO. 16

Film Badge Services ¹

Section 1. General

- 1.00 **NEED:** For some years there has been concern about the ability of film badge services, commercial, governmental, and other, to report radiation exposures with suitable accuracy and reliability. This concern has been supported by the results of unpublished tests and by a few published tests (1-5). One manifestation of this concern has been consideration, by the U.S. Atomic Energy Commission, of the establishment of a laboratory to test film badge services against certain standards of performance (6).
- 1.01 **SCOPE:** This standard describes techniques for measuring the accuracy of film badge services and establishes control limits that constitute minimum acceptable performance. The standard applies to radiation monitoring services known as film badge services. It is intended to apply to private, governmental, profit and nonprofit organizations, or individuals.
- This standard shall serve as a guide and shall in no way restrict development of new techniques, products or services.
- 1.02 **MINIMUM REQUIREMENTS:** The requirements of this standard are minimum requirements. Film badge services should strive to provide accuracies better than those essential to satisfactory compliance with this standard.
- 1.03 **STANDARD REVIEW:** A complete review of the Standard shall be conducted at intervals of not more than 3 years to determine what changes, deletions, or additions, if any, are necessary to maintain current and effective requirements consistent with new technology and progress. These reviews shall be conducted by appropriate representatives from the industry, public health, and user groups. Final adoption of

¹ The research leading to the establishment of this standard was sponsored primarily by U.S. Public Health Service Contract No. PH-86-63-198 with the National Sanitation Foundation.

revisions shall be in accordance with the procedures established by the National Sanitation Foundation.

Section 2. Definitions

- 2.00 **FILM BADGE SERVICE:** Any organization or individual processing film badges for the purpose of evaluating the quantity of radiation to which an individual or group of individuals is exposed.
- 2.01 **UNITS:** The film badge cannot measure dose equivalent (rem) directly (7). However, for the purpose of this Standard, irradiations shall be reported in dose equivalent units. Table 1 lists the units used here to describe film badge irradiations. Tables 2 and 3 give further details on the units and standards used.
- 2.02 **EFFECTIVE ENERGY (keV):** The effective energy calculated using the first half-value-layer after the method described by Johns (10).

Section 3. Sources and Standards

- 3.00 **SOURCES:** The sources used to irradiate film badges and the instruments used as the reference standards for irradiations are listed in table 2.
- 3.01 **RADIATION STANDARDS:** The Standards for gamma and X-radiation exposures shall be Victoreen Condenser R-meters for which correction factors have been determined by the National Bureau of Standards within the energy ranges included in the test (11).

An extrapolation chamber shall be used to measure beta radiation doses. It shall be calibrated both electrically and

Table 1. Irradiation units

Radiation	Units taken to be equivalent to 1 rem
X and gamma.....	Roentgen
Beta.....	Rad
Fast neutron.....	$2.6 \times 10^7 \text{ n/cm}^2$ *
Mixed	
X + gamma.....	Roentgen + roentgen
Beta + gamma.....	Rad + roentgen

* References 8, 9.

Table 2. Sources and Standards

Source of radiation	Nominal activity	Source covering	Calibration reference
G. E. Maxitron 300 X-ray machine ^a	—	4.75 mm beryllium window	Models 70-5 and 651, Victoreen R-meters, calibration by NBS ^b
Cesium 137	60 mCi	30 mils, 303 S.S. +30 mils, 321 S.S.	Model 552 Victoreen R-meter, calibration by NBS
Strontium-yttrium 90	5 mCi	21 mg/cm ² aluminum end window	Extrapolation chamber calibration by NSF ^c
Plutonium-beryllium	1 Ci	100 mils tantalum	MnSO ₄ bath, calibration by NBS

^a Used with not less than 1 mm Al added filtration.

^b The National Bureau of Standards, Washington, D.C.

^c The National Sanitation Foundation, Ann Arbor, Michigan.

by comparison with a natural uranium slab. The error in beta radiation exposures measured with the extrapolation chamber shall not exceed 10 percent.

The emission rate in neutrons per second of the neutron source shall be measured by the National Bureau of Standards.

Section 4. Irradiations

4.00 IRRADIATIONS: Irradiations shall be made as indicated in table 3.

Primary radiation shall be directed toward the front of the film badge in all test irradiations.

Irradiations shall be made when laboratory relative humidity is between 10 and 50 percent and air temperature between 24 and 27 degrees Celsius. Relative humidity shall be measured either with a sling psychrometer or with an instrument calibrated by comparison therewith.

Table 3. Irradiations per test

Group	Radiation	Source or energy	Irradiation range	Number of film badges ^a	Type of film
1	Gamma	Cesium 137	20-600 mR	9	Beta-gamma
2	Beta	Strontium-yttrium 90	40-600 mrad	9	Beta-gamma
3	Beta and gamma ^b	Strontium-yttrium 90	40-600 mrad	9	Beta-gamma
4	X-ray ^c	Cesium 137	20 mR-500R	31	Beta-gamma
5	X-ray and gamma	15-200 keV	20-600 mR	9	Beta-gamma
6	Fast neutron	15-30 keV	20-600 mR	9	Neutron
7	Controls	Cesium 137	50-600 mrem	9	Neutron
8	Controls	Plutonium-beryllium	0	2	Beta-gamma
		Background	0	2	Neutron
Total				80	

^a To be used in annual evaluations.

^b One group of nine film badges irradiated with a mixture of beta and gamma radiation. When reports are received from film badges services, the beta and gamma components for this group are examined separately and compared with different criteria. See table 4.

^c Three groups of nine film badges and one group of four. Each group is compared separately with criteria in table 4.

4.01 GAMMA RADIATION: Gamma radiation exposures shall be made with a cesium 137 source. The source shall be centered in a 2-mm thick Plexiglas receptacle in the middle of the 1-meter-diameter Plexiglas ring as shown in figure 1. Badges shall be mounted on the inside of the ring.

Except for bearings and baseplate, the rig shall be made of Plexiglas and aluminum and shall be as close to zero mass as mechanics will allow. The rings will rotate during exposures to smooth out errors caused by either source anisotropy or anisotropic scatter from laboratory structures.²

4.02 BETA RADIATION: Film badges shall be irradiated with beta rays from a low bremsstrahlung, strontium-yttrium 90 source. Film badges shall be placed so that the front of the film wrapper, regardless of type of badge, is located between 18 and 20 cm from the source.

The smaller Plexiglas ring shown in figure 1 shall be used to hold film badges for beta irradiations (figure 2).

² This rig and the one used for neutron irradiations are similar in principle to those used by the Atomic Energy Commission at Idaho Falls (12).

Measurements of beta dose rate shall be made with a duplicate of the beta ring from which a section is cut to permit measurements with an extrapolation chamber. Measurements shall be made with the extrapolation chamber at various positions around the source, as shown in figure 3. Also, measurements of the beta radiation dose shall be made with film on the small diameter ring of the apparatus shown in figure 1 to confirm extrapolation chamber measurements of dose rate distribution. The distribution of dose rates around the source used by the National Sanitation Foundation is shown in figure 4.

- 4.03 X-RADIATION: Film badges shall be exposed to the primary beam of a filtered X-ray machine operated in the region of 65–300 kVp. The quality of X-ray beams shall be defined in terms of effective energy based on half-value-layer measurements made with Victoreen Condenser R-meters (10). The kVp, beam filtration, and first and second half-value-layers shall be specified as a part of the test results. The minimum added filtration shall be 1 mm of aluminum.

Film badges shall be supported in the beam by an air equivalent platform of the type shown in figure 5.

- 4.04 FAST NEUTRONS: The rig for neutron irradiations, shown in figure 6, shall be made of aluminum except for bearings and baseplate. The source shall be placed with its long axis normal to the front of the film badges and held in place by an aluminum tube 2-mm thick.

A plutonium-beryllium neutron source shall be used to irradiate badges containing neutron-detecting films at a source-to-film distance of 20 cm.

- 4.05 MIXED IRRADIATIONS: Each component of mixed irradiations shall be delivered separately using the same sources and equipment already described in this Standard.

Section 5. Analysis

- 5.00 DATA TABULATIONS: When irradiations are reported with either the prefix "greater than" or "less than," the reported numeral shall be used in the annual analysis.

Reported mrem shall be tabulated according to the type and energy of radiation with which film badges were irradiated irrespective of the type or energy of radiation indicated in reports by film badge services. For example, if a film badge service identifies 30 keV X-rays as beta radiation, the reported irradiations shall be tabulated as 30 keV X-rays.



Figure 1. Film badge exposure rig for beta and gamma irradiations. The gamma ray source is at the top of the Plexiglas rod in the center of the upper ring. The beta ray source and holder are shown in figure 2. The smaller diameter ring supports film badges during beta irradiations. The larger diameter ring supports film badges during gamma ray exposures.

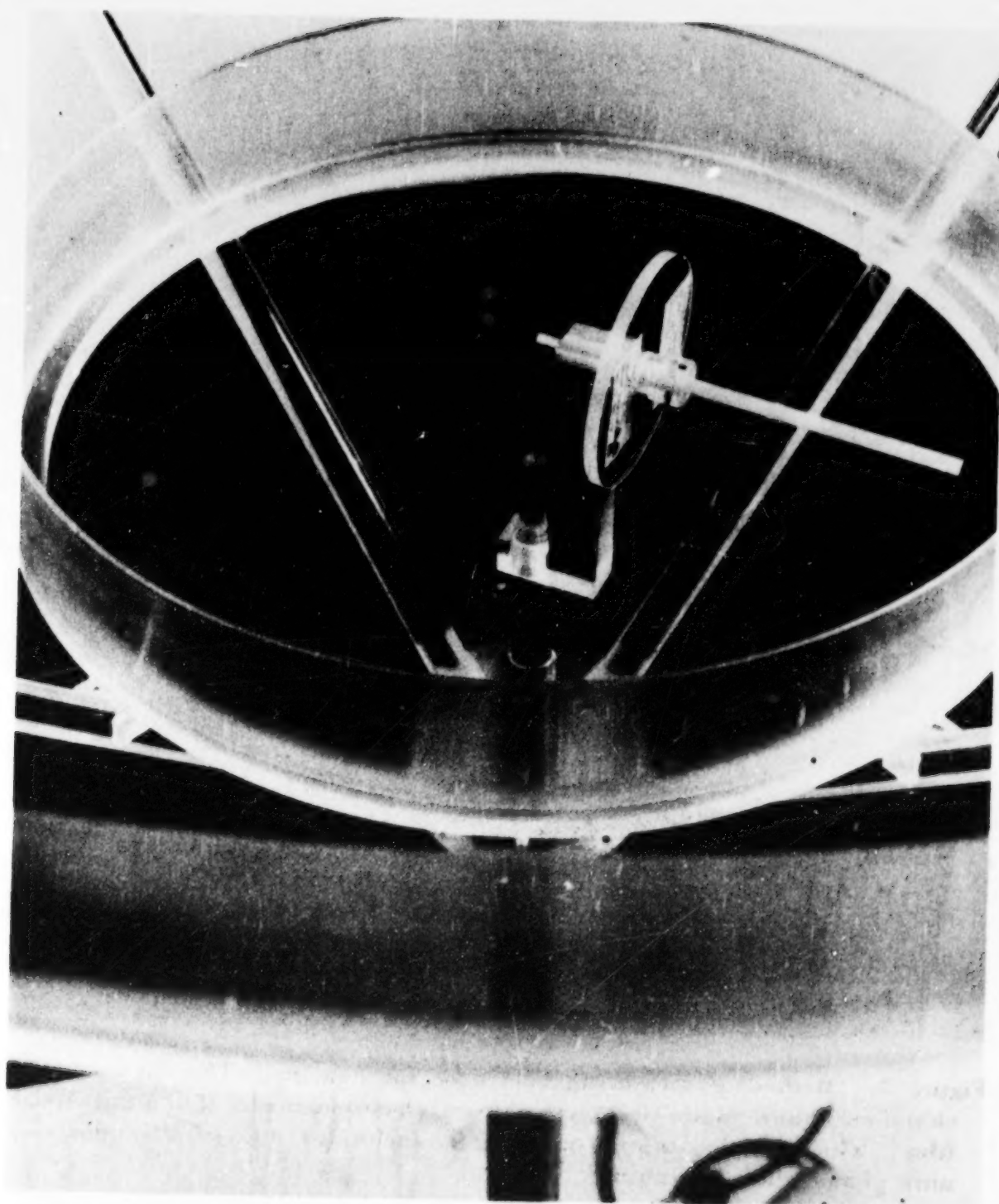


Figure 2. Strontium-yttrium 90 beta source and holder. The source is embedded in the end of the small aluminum cylinder shown in the center of the figure. The source holder is designed so that the source can be positioned in the center of the Plexiglas ring which supports the film badges during irradiation.

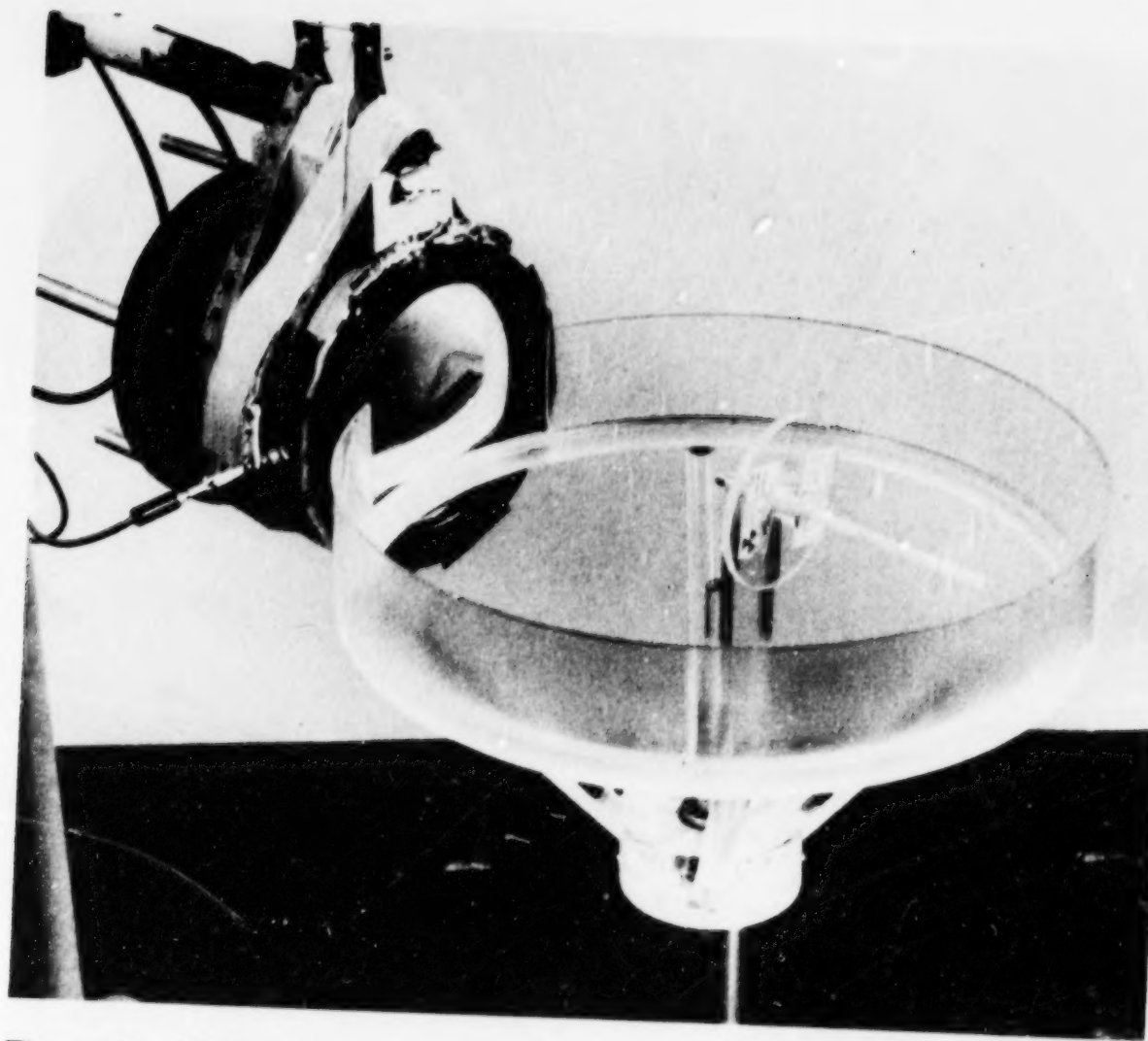


Figure 3. Method of measuring beta dose rates in air. The extrapolation chamber, shown to the left, has a front electrode made of 0.5-mil Mylar film. The rear electrode is made of 0.5-inch-thick disk of Plexiglas vacuum plated with aluminum.

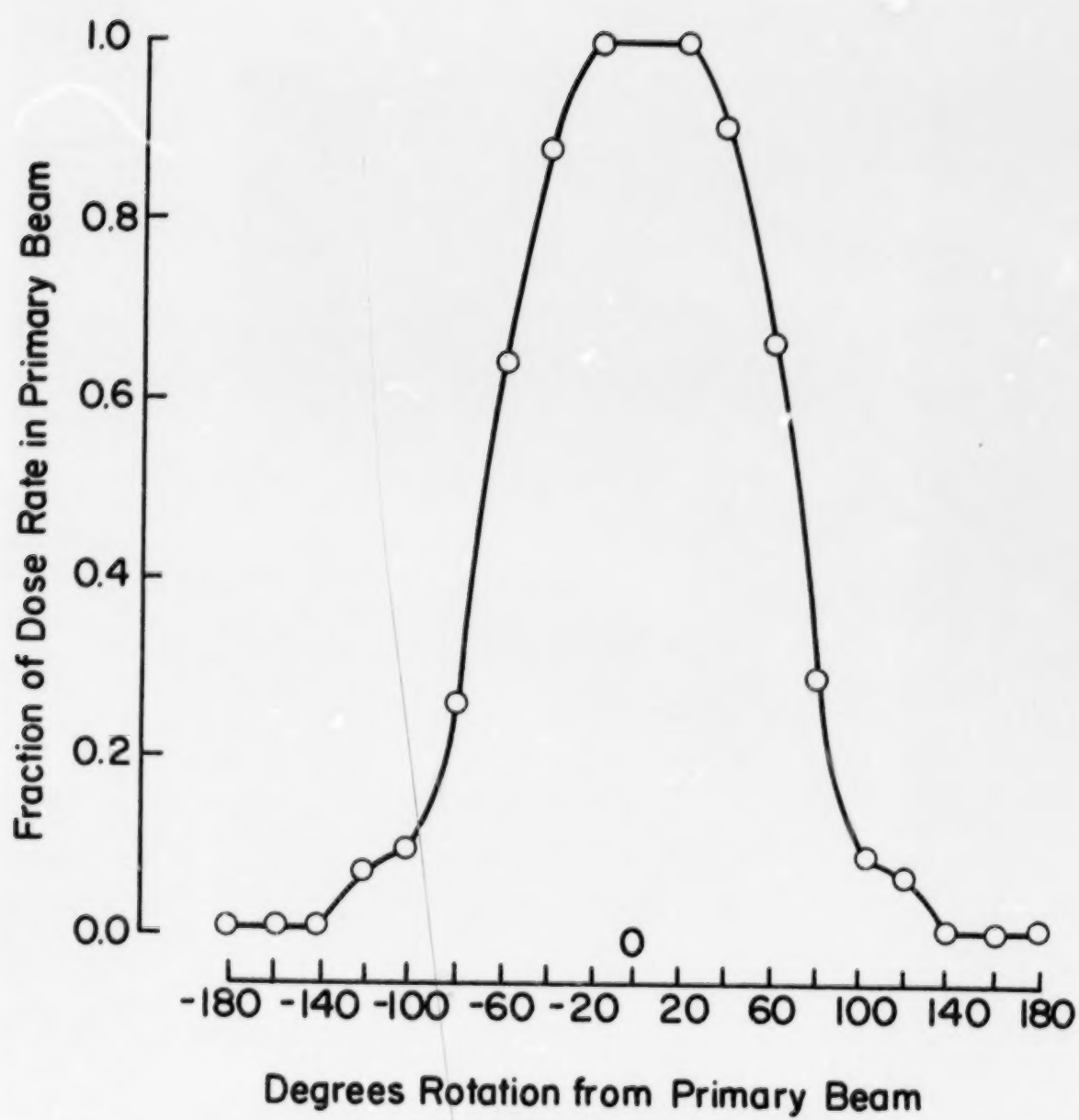


Figure 4. Angular distribution of beta dose rate in air around the strontium-90 source.

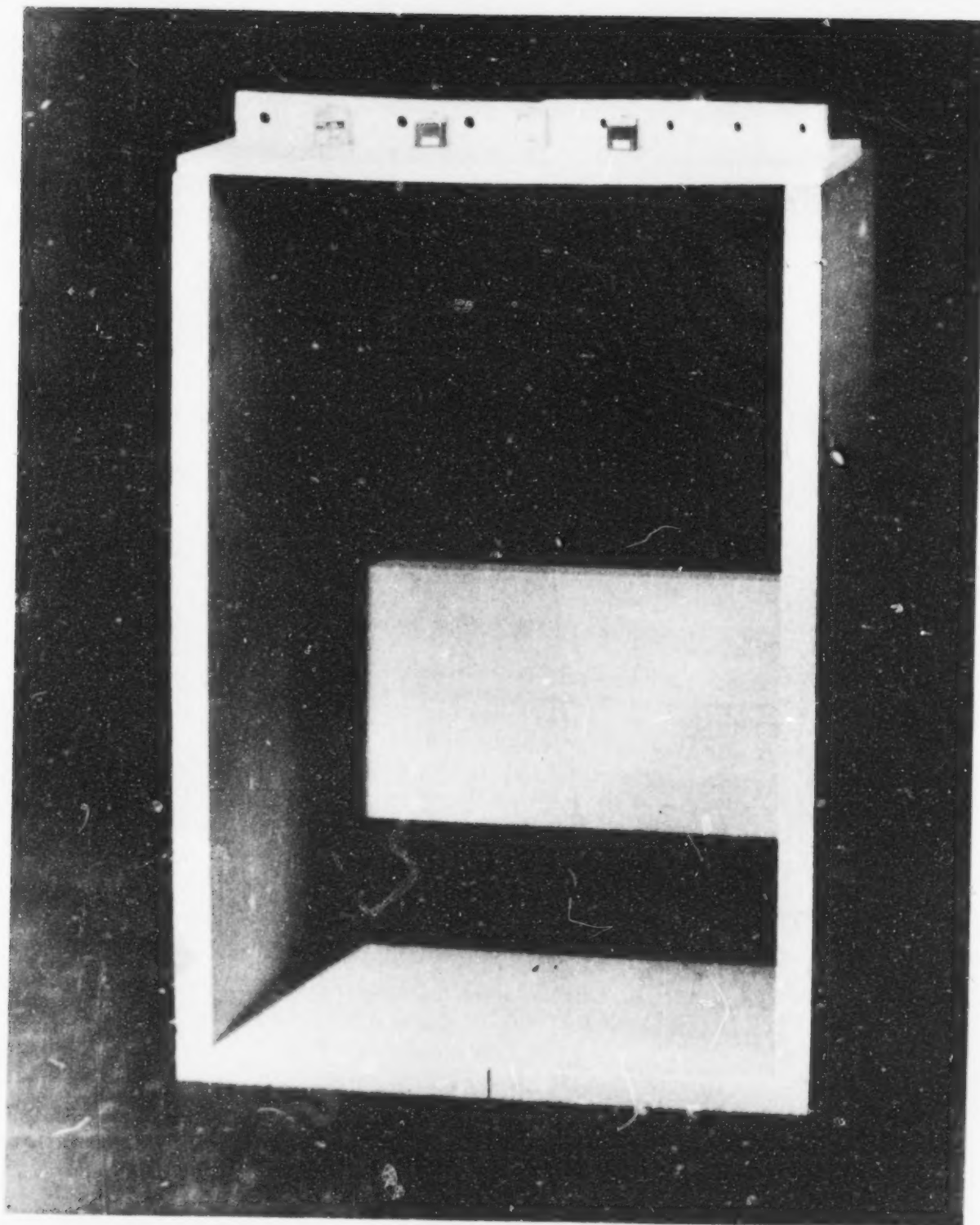


Figure 5. Styrofoam platform used to support film badges during X-ray exposures. Badges stand in front of the white riser with holes in it. The holes permit X-ray measurements to be made with an end-window Victoreen Condenser R-meter.

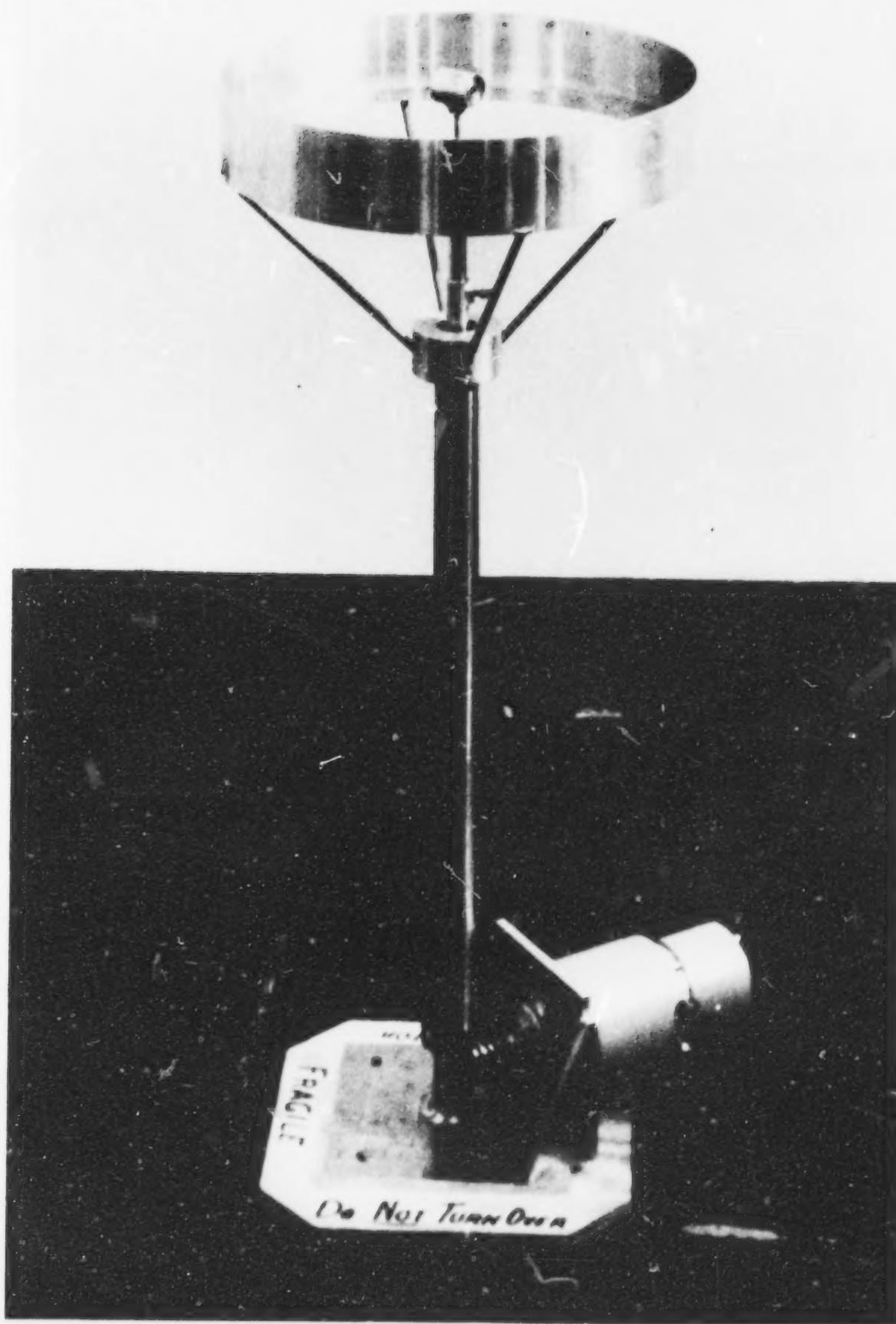


Figure 6. Neutron irradiation rig. The source can be seen inside the aluminum sleeve shown in the center of the figure. The source is positioned in the sleeve so that the activity is centered in the middle of the aluminum ring which supports film badges during irradiation.

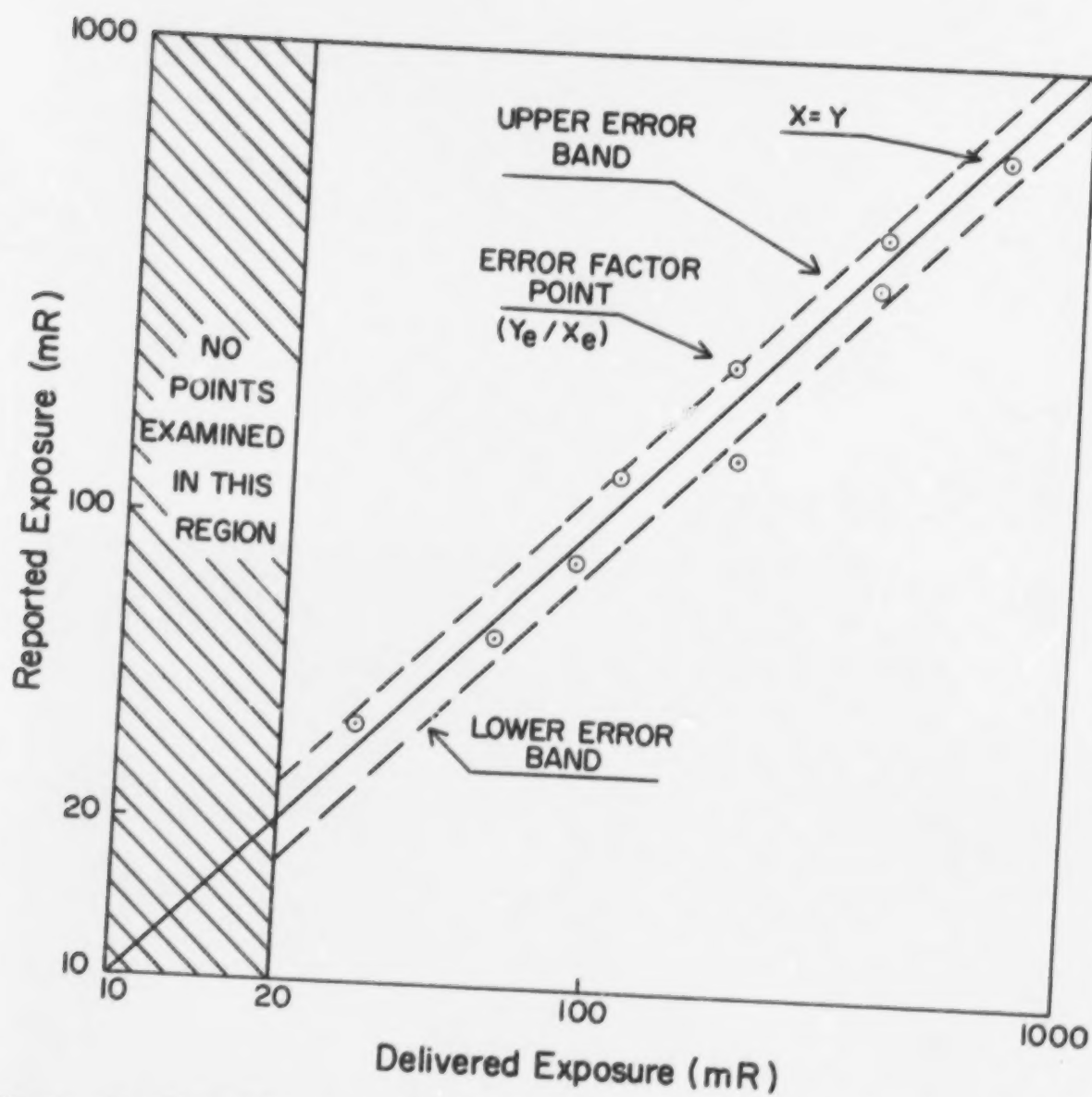


Figure 7. Example data showing a method of selecting the reported exposure used to determine the error factor.

All reported irradiations shall be assumed to be net results unless the film badge service specifies otherwise and reports irradiations for control film badges.

- 5.01 **ERROR FACTOR:** Let k be the number of film badges in each radiation group in table 3. The error factor (Y_e/X_e), where Y_e is the reported irradiation and X_e is the delivered irradiation, shall be selected so that percentage error bands which it represents $(1-Y_e/X_e)$ 100 percent, will encompass $k-1$ of the data points. In the data upon which this standard is based, the error factor represented the second largest percentage deviation from the delivered irradiation. Situations might arise, however, where this would not be true. Figure 7 illustrates a method of selecting the reported exposure used to calculate the error factor.

The error factor shall be computed separately for the gamma and beta components of mixed beta and gamma irradiations.

Section 6. Control Limits

Compliance with this Standard requires that film badge services demonstrate ability to report test irradiations within the control limits given in table 4. Note in table 4 that two groups of nine

Table 4. Film badge performance control limits ^a

Radiation category ^b	Irradiation range for test	Error factor control limits		Percentage error band ^c	
		Upper	Lower	Upper	Lower
X-rays, 15-30 keV.....	20-600 mR	1.50	0.67	50	33
X-rays, 0.03-0.2 MeV.....	20-600 mR	1.70	0.59	70	41
X-rays, 0.15-0.2 MeV.....	1-500 R	1.60	0.63	60	37
Gamma, 0.2-3 MeV.....	20-600 mR	1.40	0.71	40	29
Beta.....	40-600 mrad	1.50	0.67	50	33
Beta of $\beta + \gamma$	40-600 mrad	2.00	0.50	100	50
Gamma ^c of $\beta + \gamma$	20-600 mR	1.40	0.71	40	29
X ^d + gamma ^e	20-600 mR	1.90	0.53	90	47
Fast neutron.....	50-600 mrem	2.00	0.50	100	50

^a Energy ranges and types of radiation involved in the test are known to the film badge services but the type and energy of radiation delivered to a specific badge is unknown.

^b Sources are described in detail in table 2.

^c $(1-Y_e/X_e)$ 100.

^d X-rays of 15-30 keV.

^e Gamma rays of 0.2 to 3 MeV energy.

film badges are involved in the 0.03 to 0.2 MeV X-radiation category. Therefore, compliance with this Standard involves performance tests in 10 separate radiation categories for those organizations that offer beta, gamma, and neutron monitoring services. For organizations offering only beta and gamma monitoring services, the test involves nine separate radiation categories.

The intent of this Standard is that the error bands represented by the error factor encompass all but one ($k-1$) of the data points in each radiation category. Consequently, a service complies with the Standard only if $k-1$ of the data points in each radiation category fall within the error bands represented by the error factor.

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THE NATIONAL SANITATION FOUNDATION
ADMINISTRATIVE POLICY FOR FILM BADGE EVALUATIONS

NOVEMBER 1965

Seal of Approval

The Standard applies to specific irradiation ranges. Therefore, compliance with the Standard does not indicate the accuracy of services outside the irradiation ranges specified.

One complete test involving radiation categories provided by the film badge service and covered by the Standard must be accomplished each year.

Film badge services that demonstrate error factors within the control limits for all the radiation categories specified in the Standard are eligible to use the nSf Seal of Approval as a symbol of their compliance with the Standard. Applications for use of the Seal of Approval will be examined 9 to 12 months after first irradiations are made in accordance with the Standard. This grace period is to provide time:

1. for services to meet the requirements of the standard, and
2. to examine the data from the first Standard test to determine the appropriateness of the requirements.

A separate annual publication called the nSf Seal of Approval Listing will be distributed widely to customers and potential customers of film badge services. This publication will list those services that comply with the Standard. Quarterly supplements to this list will be published.

Film badge services that fail to meet all of the control limits in the Standard will be informed of those portions of the Standard they failed. The Foundation will then decide, in consultation with the film badge service, the extent to which the service must be reexamined to be eligible to apply for use of the Seal of Approval. All test data will be returned to participating film badge services.

A service may be retested at its own expense as frequently as it wishes.

The Foundation will conduct unannounced spot checks of a service's performance by obtaining film badges from one or more of the service's customers. The number of films obtained will be sufficient for providing a performance check of one or two radiation categories in the Standard, depending upon the needs of the customer.

For the spot check evaluations it is essential that film badge services provide the Foundation with the conversion factors normally used by them to convert:

1. neutrons/cm² to mrem,
2. beta mrep to mrad, and
3. mR to mrad.

Film badge services will also provide the Foundation with a list of their customers. This information and the above conversion factors shall be strictly confidential between the Foundation and the service which provides the information.

A service will be advised by the Foundation when it fails a spot check. The Foundation, in consultation with the service, will then decide whether or not a second spot check, at the expense of the service, is necessary for compliance with the Standard.

Film Badge Handling

Film badge services will submit film badges for a complete set of test irradiations, at least once a year on a prearranged schedule. Badges will be stored until badges from a number of different services have been received or until not more than 30 days have elapsed after the first set of badges was received. Immediately after the irradiations are completed all badges will be returned to their suppliers for processing and interpretation.

It is to the advantage of most film badge services to report their interpretations as soon as possible after the test badges are returned to them; consequently, no limitation on reporting time is specified.

Film badges submitted for retest will be irradiated immediately and returned to the suppliers unless the retest involves all radiation categories.

All badges received by the Foundation will be stored together in an air-conditioned building until irradiations are completed and badges returned to suppliers. Each badge will be marked with removable code letter to: (1) preclude mixing of badges of a single service submitted by different suppliers, and (2) simplify data handling in a manner that prevents identification of individual services from tabulated test results.

The Foundation will arrange with customers of film badge services to obtain film badges for spot checks.

Standard Review

A complete review of the Standard shall be conducted at intervals of not more than 3 years to determine what changes, deletions, or additions, if any, are necessary to maintain current and effective requirements consistent with new technology and progress.

THE ABSTRACT CARDS accompanying this report are designed to facilitate information retrieval. They provide space for an accession number (to be filled in by the user), suggested key words, bibliographic information, and an abstract. The key word concept of reference material filing is readily adaptable to a variety of filing systems ranging from manual-visual to electronic data processing. The cards are furnished in triplicate to allow for flexibility in their use.